ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 65 (2013) 45 – 50

Procedia Engineering

www.elsevier.com/locate/procedia

Concrete and Concrete Structures 2013 Conference

The Potential of Higher Share of Fly Ash as Cement Replacement in the Concrete Pavement

Marcela Ondova[a,*], Nadezda Stevulova[a], Ludmila Meciarova[a]

[a]*Technical University of Kosice, Faculty of Civil Engineering, Vysokoskolska 4, 042 00 Kosice, Slovakia*

Abstract

The world faces a number of environmental issues. Developments (especially technological) in our society are still of highly extensive nature and the forthcoming process of globalization significantly affects the state of the environment. There is also a slight increase in population, uncontrolled extraction of raw materials for production of materials, energy and urbanization of the environment. At the same time the amount of harmful emissions and wastes increase. Mineral resources are considerably limited. As well as limited resources to feed a growing population (problems of drinking water and food) limited resources and materials needed for construction of buildings, infrastructure development and industry provision to further ensure the welfare of people. It follows the need for change of approach in area of civil engineering. Concrete is the most used building material in the world, but unfortunately it also leaves a major carbon dioxide emission. In building industry, it includes cutting back carbon dioxide emissions by using less energy consumptive materials - that is, by maximizing use of waste products. Many articles have been written on how this industry can contribute. This can occur in a number of ways and one of them is use substitutes for Portland cement with waste products such as fly ash, ground-granulated blast furnace slag cement, rice hull ash, silica fume, pozzolans of all types, and ground limestone, in the process of concrete production. This paper is focused on the possibility of using fly ash to replace cement in concrete pavement. Mechanical properties, chemical resistance, freezing and thawing of fly ash concrete were measured and compared with the reference specimen (C 30/37), which met the requirements of STN 73 6123. Besides, the economic assessment of costs of both concretes (with/without fly ash) was made. Finally, environmental benefits of brown coal fly ash utilization in the area of Slovak road engineering based on its life cycle analysis are also presented.

Selection and peer-review under responsibility of University of Zilina, Faculty of Civil Engineering, Department of Structures and Bridges

Keywords: Concrete; fly ash; life cycle assessment; mechanical properties of fly ash concrete, road pavements;

* Tel.: +421556024286
E-mail address: marcela.ondova@tuke.sk

Selection and peer-review under responsibility of University of Zilina, Faculty of Civil Engineering, Department of Structures and Bridges
doi:10.1016/j.proeng.2013.09.009

1. Introduction

The concrete industry is the largest consumer of virgin materials such as sand, gravel, crushed rock, and fresh water. It is consuming Portland and modified Portland cements at an annual rate of about 1.6 billion metric tons [1]. In addition to consuming considerable amounts of nature materials (limestone and sand) and energy, production of each ton of Portland cement releases one ton of carbon dioxide (CO_2) into the environment. Concerns for the sustainable development in the cement and concrete industries are increasingly addressed [2]. In the long run, sustainable development of the concrete industry will not take place until we are able to make even more dramatic improvements in our resource productivity. In this context, it should be noted that the Factor Ten Club, a group of scientists, economists and business people have made a declaration that, within one generation, nations can achieve a tenfold increase in their resource productivity through a 90% reduction in the use of energy and materials [2]. One of the concrete technologies for sustainable development is to use "green" materials for construction. The "green" materials are considered as materials that use less natural resource and energy and generate less CO_2 [3-6]. Simply defined, the practice of industrial ecology involves the reclamation and re-use of its own waste products and, to the extent possible, the waste products of other industries which are unable to recycle them in their own manufacturing process. Fly ash, a principal by-product of the coal-fired power plants, is well accepted as a pozzolanic material that may be used either as a component of blended Portland cements or as a mineral admixture in concrete. The large scale potential applications of fly ash utilization in construction industry depends on more reliable research results that envisages the beneficial effects of fly ash in concrete [7-9]. In commercial practice, the dosage of fly ash is limited to 15%-20% by mass of the total cementitious material. Usually, this amount has a beneficial effect on the workability and cost economy of concrete but it may not be enough to sufficiently improve the durability to sulfate attack, alkali-silica expansion, and thermal cracking. Higher amounts of fly ash in the order of 25%-30% are recommended when there is a concern for thermal cracking, alkali-silica expansion, or sulfate attack. Such high proportions of fly ash are not readily accepted by the construction industry due to a slower rate of strength development at early age [10].

Slovak technical standards established requirement for use of additives to a maximum of about 5-8%. Subsequently, in 2010 the use of additives was rejected by the amendment of technical standards. However, the Slovak brown fly ash produced by heat and power plant is useful in road construction too. Thanks to fly ash properties as well as thanks to our obtained results is the fly ash suitable partial cement replacement (15 wt. %) in concrete pavements. Mechanical characteristics of concrete composites with fly ash met the Slovak and European Technical Standards. Pointed economic benefits present fly ash as gainful alternative for building industry. Values of hazardous substances in fly ash as well as results of environmental profiles show other advantages and potential of fly ash utilization in the field of construction industry as well as in the field of construction materials production. The results of the processing of comprehensive analysis according to our proposed method in the field of life cycle assessment of fly ash concrete confirmed the suitability of Slovak fly ash as appropriate resource of alternative raw material [11].

2. Material and Methods

2.1. Material

To study the possibility of fly ash (FA) utilization in concrete pavements (max. 15% cement replacement), the Slovak FA from brown coal combustion of the power plant Novaky (the chemical composition is presented in Table 1) meeting the requirements according to the STN EN 450 – Fly ash in concrete, was chosen.

Table 1. Chemical compositions of fly ash

Component [wt. %]															
SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	MnO	P_2O_5	SO_3(S)	S_{total}	LOD	LOI	C.Sub.	ROC
37.5	15.60	7.67	1.30	22.94	2.77	1.21	0.63	0.11	0.18	7.29 (2.91)	2.91	0.16	2.59	2.14	0.28

*Loss of drying (LOD), Loss of ignition (LOI), Combustible substances: 830 °C (C.Sub.), Residual organic carbon (ROC)

In accordance to the proposed prescription, the C 30/37 grade concrete was prepared with 0-15% FA replacement of Portland cement CEM I 42.5 N. Water/binder ratio was 0.36 and natural gravel aggregate from stone (pit Soporna and Hanisberk) in specific ratio of the fine to coarse aggregate 40 (0/4): 10 (4/8): 50 (8/16, 16/32) was used in the mixture (the final grain size distribution of aggregate is shown in Figure 1).

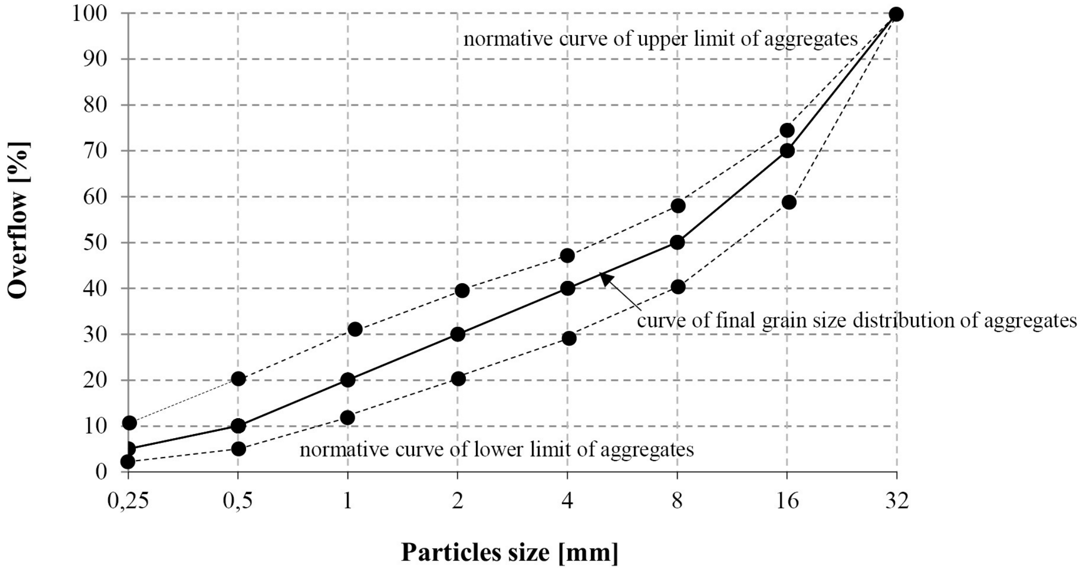

Fig. 1. Final grain size distribution of aggregates used in concrete

2.2. Methods

The mixtures were prepared in the laboratory mixer type ZZ 150 SH. Three basic properties of freshly mixed concrete: consistence, air content and temperature (EN 206-1: 2002) were tested according to requirements of EN 12350 (parts 3 and 7; Table 2) before the forms were filled. Table After 28 days of hardening, the composites were tested on compressive strength (CS), flexural strength (FS), determination of concrete de-icing salts resistance (STN 73 1326, STN 73 6123) as well as on freezing and thawing. The resulting values of experimental FA composites were compared with requirements of Technical standards (TS) (CS – 32. 0MPa / 28d, FS – 4.5MPa / 28d). Subsequently, the contents of harmful elements on human body as Cr^{VI} and ^{40}K, ^{226}Ra, ^{232}Th of cement and fly ash as well as their contents after stabilization in fly ash concrete mixture were monitored [14]. At the end, the life cycle assessment (LCA) of alternative concrete, which was carried out according to [15] was studied. It is defined as tool that can be used to identify ways to decrease the environmental impact of a product or process and to inform decision makers of the consequences of changes to the product or process and it encompasses all aspects of a process or product from "cradle to grave", including material extraction, transport, production, maintenance, and removal or recycling [16].

3. Results and Discussion

3.1. Concrete tests

The measured values of fresh concrete properties and hardened composites properties in comparison with the specific requirements of Technical Standard are presented in Table 2, 3. As it can be seen, in the consistency test all samples comply with requirement of S1. Improvement in consistency is slightly visible with increasing amount of fly ash. Air content met technical requirement of 4-8% and the amount of fly ash does not influence the air content significantly. Temperature tests showed that all samples met standard requirement for temperature range of $+5°C \leq T \leq +30°C$. Increasing amount of fly ash is causing slight decrease in temperature. But it is logical, due to decrease of hydration heat causing by smaller amount of clinker. Compressive and flexural strengths development of composites based on various fly ash portions after 28 days as well as the de-icing salts and frost resistance are shown in Table 3. Based on these results it can be stated that the prepared FA concrete composites with 5 % as well as 15 % of cement replacement met the required criteria of the Technical standard. With increasing amount of fly ash, slight decrease in both strengths is visible - early and final strengths. De-icing salt resistance requirement (max. 300 g/m^2 of scaling in 100 cycles) is not fulfilled only in case of 15% wt. FA cement replacement. However, it is necessary to say that testing was done under more strict conditions – 150 cycles. In paper [12], the scaling value of 1500 g/m^2 is classifying as small damage, while according to laboratory testing such samples did not show any degradation even at real exposure. All samples met requirement for min. 0.85 in assessment area of frost index. Increase in fly ash content is causing decrease of frost index. Standard requirement for value of compressive strength after freezing cycles does not defined; however we were included this in our testing. As per results, compressive strengths after freezing cycles increased slightly. Increasing amount of fly ash basically doesn't influence values of strength after freezing; decrease is only visible after 15% replacement [13].

Table 2. Results of fresh concrete tests

Parameter	Unit	Required value	5 % of FA	10 % of FA	15 % of FA
Slump test	[mm]	S1(10-40mm)	30	40	40
Air content	[%]	4-8	6.0	6.4	6.5
Temperature	[°C]	$+5 \leq T \leq +30$	22.5	19.5	19.5

Table 3. Results of hardened concrete tests

Parameter	Unit	Time of testing	Required value	5 % of FA	10 % of FA	15 % of FA
Flexural strength	[MPa]	28 d	4.5	6.6	6.2	5.6
Compressive strength	[MPa]	28 d	32	44.2	42.4	37.2
De-icing salts resistance – Scaling	[g/m^2]	after freezing	max. 300	90.7	209.1	257.0
Frost resistance: Flexural strength	[MPa]	before freezing	-	6.5	6.2	5.8
		after freezing	-	5.9	5.6	5.1
: Resistant index	[%]	-	min. 0.85	0.91	0.90	0.88
Compressive strength	[MPa]	before freezing	-	45.3	42.7	38.2
		after freezing	-	50.6	50.6	42.7

3.2. Monitoring of harmful elements

Results of hazardous elements content is summarized in Table 4. Determination of hexavalent water-soluble chromium as well as of radioactivity (^{226}Ra, ^{228}Th, ^{40}K) of cement CEM I 42.5 N and fly ash meet the world criteria specified for Cr^{6+}: max. 2ppm (ppm = mg/kg) and for gamma index (calculated of ^{40}K, ^{226}Ra, ^{232}Th) : <1. For the comparison, the gamma index of concrete composites without (reference sample - RS) and with a 15 wt. % fly ash as substitution of cement were measured. Total content of Cr^{VI} decreased to the value 0.05ppm (FA composite) and to 0.07ppm – value of reference sample. Value of gamma index decreased to 0.146 (FA composite) and 0.140 (RS). Based on these results of the environmental assessment it can be stated that the fly ash under discussion is suitable for its use as cement substitute in concrete.

Table 4. Summary of the harmful elements tests

Tested hazardous elements	Unit	Fly ash	CEM I 42.5N	Reference sample	FA concrete
Cr^{VI}	mg/kg Cr^{6+}	0.01	2.46	0.07	0.05
Radioactivity: ^{226}Ra	[Bq/kg]	39.259	13.081	8.609	6.463
^{232}Th	[Bq/kg]	10.144	19.839	22.258	24.925
^{40}K	[Bq/kg]	698.167	169.232	397.18	199.41
Gamma index Iγ	-	0.411	0.198	0.140	0.146

3.3. Life cycle assessment of concretes

Results of LCA of FA and reference concrete samples are presented in Figure 2. As it can be seen, the fly ash concrete in comparison to reference sample has significantly better indicators of LCA (lower environmental impacts) in each area of evaluation (PEI - Primary energy intensity, POCP - Photochemical ozone creation potential, ODP - Ozone layer depletion potential, NP - nutrient potential, GWP - Global Warming Potential, AP - Acidification Potential).

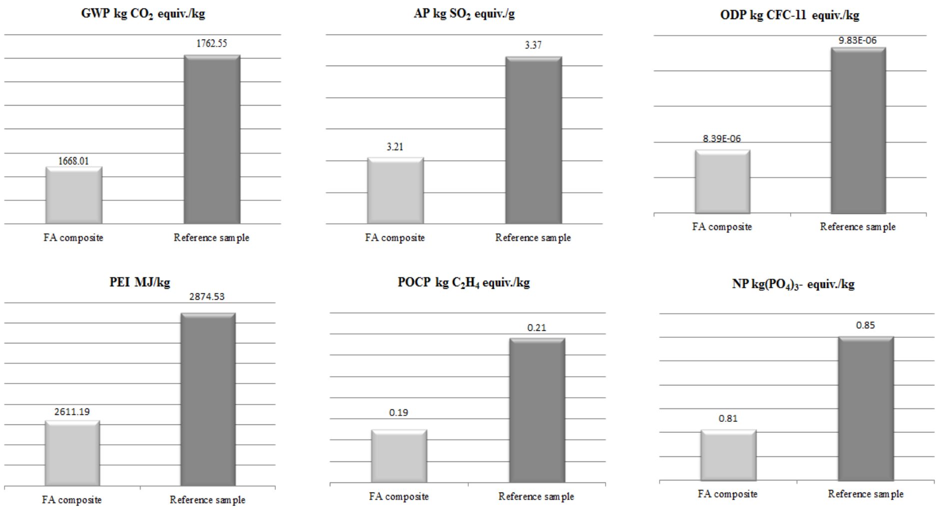

Fig. 2. Life cycle assessment results

3.4. Multi Criteria Analysis

For the final evaluation of the investigated areas (the quality parameters of freshly mixed concrete and composites, environmental parameters as well as economic benefits identified in the work [17]) two multi criteria analysis - Fuller triangle method (MA1) and Saaty´s method (MA2) were chosen. Both analyzes were converted through the Weighted Sum Approach; Ideal Points Analysis; Technique for Order Preference by Similarity to Ideal Solution and Concordance/Discordance Analysis. In the case of MA1 the environmental criteria were preferred. In the second case (MA2), the same weights of importance of all environmental impacts and the parameters of strength and durability were assigned. The results showed that the concrete with a fly ash cement replacement appear to be a better variant, but also it is necessary to note that both of these options have advantages and disadvantages. One disadvantage of fly ash concrete is its lower strength compared to the reference concrete. Although it must be stated that the strength requirements of Slovak technical standards (CS – 32.0MPa, FS – 4.5MPa) have been met, even were exceed with fly ash concrete.

4. Conclusion

Cement is one of the raw materials, which has among the industrial construction materials a significant place. At the same time, its production leads to significant energy consumption and natural resources extraction. Besides, it produced large amounts of CO_2 and other pollutants. Therefore, around the world scientists are looking possibilities for reducing of the said impacts to the environment. As the research results, one of the advantageous ways is the utilization of Slovak brown coal fly ash, which seems to be indicated by a suitable cement replacement in the construction of new Slovak road networks (with respect to results of all evaluated areas).

Acknowledgements

This research has been carried out in terms of the project NFP 26220220051 supported from the European Union Structural funds.

References

[1] P.K. Mehta, Durability: Critical Issues for the Future, Concrete International 19, 1997, pp. 69-76.
[2] P. Hawken, E. Lovins, H. Lovins, Natural Capitalism: Creating the Next Industrial Revolution. Little Brown and Company, 1999, p. 396.
[3] P.K. Mehta, High-performance, high-volume fly ash concrete for sustainable development, International Workshop on Sustainable Development and Concrete Technology, Beijing, 2004, pp.1-15.
[4] B. Lippiatt, S. Ahmad, Measuring the life-cycle environmental and economic performance of concrete: the BEES approach, International Workshop on Sustainable Development and Concrete Technology, Beijing, 2004, p. 213.
[5] E. Masanet, L. Price, S. De la Rue du Can, R. Brown: Reducing greenhouse gas emissions from products manufactured in California, 2nd annual Climate Change Research Conference, Sacramento, California, 2005.
[6] H.G. Van Oss, A.C. Padovani, Cement manufacture and the environment, part II: environmental challenges and opportunities, Journal of Industrial Ecology 7, 2003, p. 93.
[7] V.M. Sounthararajan, A. Sivakumar, Strength investigations of processed high volume fly-ash based cement concrete, International Journal of Applied Engineering Research 8, 2013, p. 143-155.
[8] V.M. Sounthararajan, A. Sivakumar, Experimental studies on the effect of fineness of fly ash particles on the accelerated concrete properties, ARPN Journal of Engineering and Applied Sciences 7, 2012, p. 1644-1651.
[9] V.M. Sounthararajan, A. Sivakumar, Performance Evaluation of Metallic Fibres on the Low and High Volume Class F Fly ash based Cement Concrete, International Journal of Engineering and Technology 5, 2013, pp.606-619.
[10] P.S. Surendra, W. Kejin, Development of "Green" Cement for Sustainable Concrete Using Cement Kiln Dust and Fly Ash, International Workshop on Sustainable Development and Concrete Technology, Beijing, 2004, pp. 15-23.
[11] M. Ondova, N. Stevulova, Environmental assessment of fly ash concrete, Chemical Engineering Transactions 35, 2013 (in press).
[12] Brandes, CH. R., Schiebl, P.: Effect of aging related to freeze/thaw and de-icing salt resistance of concretes, In: "Concrete repair, rehabilitation and retrofitting", London: Taylor and Francis Group, 2006, p. 187.
[13] M. Ondova et al.: Assessment of selected indicators of Portland cement containing fly ash in road concrete. Ad Alta: J. of Interdisciplinary Research 2, 2012, pp. 114-116.
[14] L. Palascakova, A. Estokova, M. Balintova, A. Petrilakova, Assessment of the content of chromium (VI) in selected types of cement as a part of cement eco-labelling, Pollack Periodica 6, 2011, pp. 123-129.
[15] J. Sjunnesson, Life Cycle Assessment of Concrete, Master thesis, 2005.
[16] C.D. Weiland, S.T. Muench, Life Cycle Assessment of Portland Cement Concrete Interstate Highway Rehabilitation and Replacement, Washington State Transportation Center, 2010, p. 105.
[17] M. Ondova, N. Stevulova, Benefits of Fly Ash Utilization in Concrete Road Cover, Theoretical Foundations of Chemical Engineering 46, 2012, pp. 713-718.